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ABSTRACT

Frequency doubling and optical parametric oscillation are investigated with potassium niobate in an external resonator. For frequency doubling of 860nm input, 650mW of cw blue light around 430nm has been generated for 1.35W of infrared input. In a cavity with reduced losses, overall conversion efficiency of up to 70% has been achieved. With regard to parametric oscillation with a 430nm pump, 100mW of stable cw emission from the optical parametric oscillator has been obtained for pump power 250mW. Blue-light induced infrared absorption has been discovered to have significant deleterious effects and to be the principal reason why even higher efficiencies have not been reached.

We report an investigation of cw frequency doubling and optical parametric generation with potassium niobate ($KNbO_3$). Previous work has demonstrated that frequency doubling in an external cavity is an attractive alternative to doubling within the laser cavity since it allows for independent optimization of the laser and doubling cavities. With reference to $KNbO_3$ in an external cavity, 38mW of blue output was obtained by doubling a diode laser[1] and 154mW by nonlinear mixing of diode and Nd:YAG emission.[2]

For the high-power doubling experiments that we report[3] a single-frequency $Ti{:}Al_2O_3$ laser capable of producing up to 2W of output around 840-870nm and with a linewidth of 50kHz rms was mode-matched into a ring doubling cavity resonant with the fundamental input. In our work two different external cavity designs which we denote as cavities "A" and "B" were implemented for frequency doubling at high and low fundamental powers respectively. The first doubling cavity A consisted of four flat mirrors and two lenses f=35mm together with a normal-cut $KNbO_3$ crystal of length 6mm;[4] the crystal as well as lens surfaces were AR coated for low loss at both 860 and 430nm. In spite of the quality of the coatings ((0.15%)/surface at 860nm) passive losses from the lenses reduced the cavity buildup relative to astigmatically compensated cavities with curved mirrors. However, the setup employed facilitated the exploration of a range of focussing geometries which is of special importance since it allowed fine tuning of the cavity mode to compensate for effects of thermal lensing at high power.

In our work with cavity "A" we have compared the theoretical expectation for second harmonic power P_2 versus input power P_1 with experimental results. The theoretical calculation was made for the measured in situ values of nonlinear single-pass conversion efficiency E_{NL}=0.0045W^{-1} and of passive intracavity loss of 3-4% exclusive of the input coupler (Note that for optimum focussing external to the cavity and free from its constraints, we find E_{NL} = 0.016W^{-1}). The theoretical results were for an optimum choice of transmission T of the input coupler, which itself depends upon the value of P_1. Experimental points were taken for T close to the optimum for each P_1. It is worth emphasizing that our experimental results were obtained after careful consideration of thermal lensing effects in the doubling cavity and optimization of its geometry in order to minimize these effects.[3] Up to an input power 1W and second harmonic power 0.5W, the experimental results for cw operation agree reasonably well with theory. However, for higher power levels, thermal lensing in $KNbO_3$ with a concomitant reducing in mode-matching efficiency and in E_{NL} leads to less cw blue power than predicted by the basic theory without the inclusion of thermal effects. The highest output power that we have achieved is 0.65W at output 430nm for 1.35W input at 860nm. To investigate thermal effects further, we also have results obtained for a sweeping regime of operation of the doubling cavity where thermal effects are much less important due to the short time of resonance ($\sim$1msec). These results agree reasonably well with the basic theory without thermal effects.[3]

For low-power frequency doubling with cavity B, the flexibility of adjustment of cavity focussing is not so critical as for the high-power doubling and in addition small losses are more detrimental. Cavity B is thus a folded cavity with curved mirrors with overall linear losses reduced to 0.6%. With this cavity we have reached conversion efficiency of 70% for infrared input in the range from 50mW to 200mW (e.g., 200mW of infrared input produces 140mW of blue output). In fact the conversion efficiency should have been even higher than the already impressive value of 70%. The reason that it was not as high as the basic theory predicts is that there were additional losses of infrared caused by the generated blue light. This effect of blue light induced infrared absorption is currently under investigation.

The folded cavity B with $KNb0_3$ was also employed as an optical parametric oscillator (OPO). In this case, the pump was provided by the blue light generated by cavity A. The OPO was operated with only the infrared down converted radiation resonant in the cavity; the blue pump beam experienced a single pass. Active stabilization of the length of the OPO was accomplished by injecting a counter propogating input from the original $Ti{:}Al_2O_3$ laser. The cw output of the OPO was very stable providing 100mW of IR power for 250mW of blue pump.

In summary we have reported frequency doubling in $KNb0_3$ in two different cavities with up to 650mW of tunable blue radiation around 430nm (cavity A) and conversion efficiencies up to 70% (cavity B). We have also described the stable operation of an OPO employing $KNb0_3$. The effects of blue-light induced IR absorption on the degradation of the characteristics of nonlinear devices with $KNb0_3$ will be discussed elsewhere.

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